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Final Progress Report (06/01/2010 - 06/01/15)

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Final Progress Report (06/01/2010 - 06/01/2015)

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1 Summary of report

This report summarizes the LLNL contributions to the JET Collaboration during the lifetime of the topical collaboration.

1.1 Refining the estimate of the charm cross section

Along with UC Davis graduate student Randy Nelson, and Tony Frawley of FSU, I published a paper that described our efforts to reduce the large uncertainty on the charm cross section [1, 2]. We accomplished this by generating a grid in μ_F/m and μ_R/m, the factorization and renormalization scales relative to the charm quark mass respectively, for a set of charm quark masses and then performed a χ^2 minimization in these variables. The uncertainty on the best fit values of μ_F/m and μ_R/m are determined from $\Delta\chi^2 = 1$ while the one standard deviation uncertainty in the charm cross section is obtained from the $\Delta\chi^2 = 2.3$ contour [3].

We use these same values of μ_F/m, μ_R/m and m in the FONLL approach to calculate the open charm p_T and rapidity distributions and compare with existing data. Our results for D^0 meson production are shown for midrapidity from ALICE [4] and forward rapidity from LHCb [5] in Fig. 1. The uncertainty bands are narrower than those obtained with the FONLL fiducial parameter set [6], especially at low p_T.

The results for forward lepton production in ALICE [7] are shown in the bottom of Fig. 1, both as a function of p_T in different rapidity bins (left) and rapidity, integrated over $2 < p_T < 12$ GeV (right). A substantial improvement in the uncertainty is also seen here. Note that the lepton results include contributions from $B \to \mu$ and $B \to D \to \mu$ as well as $D \to \mu$. Thus, the uncertainty here cannot be further reduced until a similar procedure has been performed on b production.

Since the same mass and scale parameters are used in the calculation of J/ψ production in the color evaporation model, we also performed a new fit to the J/ψ coefficient F_C in Eq. (1),

$$\sigma_C^{\rm CEM}(s_{_{NN}}) = F_C \sum_{i,j} \int_{4m^2}^{4m_H^2} ds \int dx_1\, dx_2\; f_i^p(x_1,\mu_F^2)\; f_j^p(x_2,\mu_F^2)\; \hat\sigma_{ij}(\hat s,\mu_F^2,\mu_R^2)\;, \qquad (1)$$

We fit the parameter for the central set and then use the same value of F_C for all 9 parameter sets that define the uncertainty band. The general agreement with the data is very good, see Fig. 2, both for the total cross section as a function of energy and for the RHIC pp data.

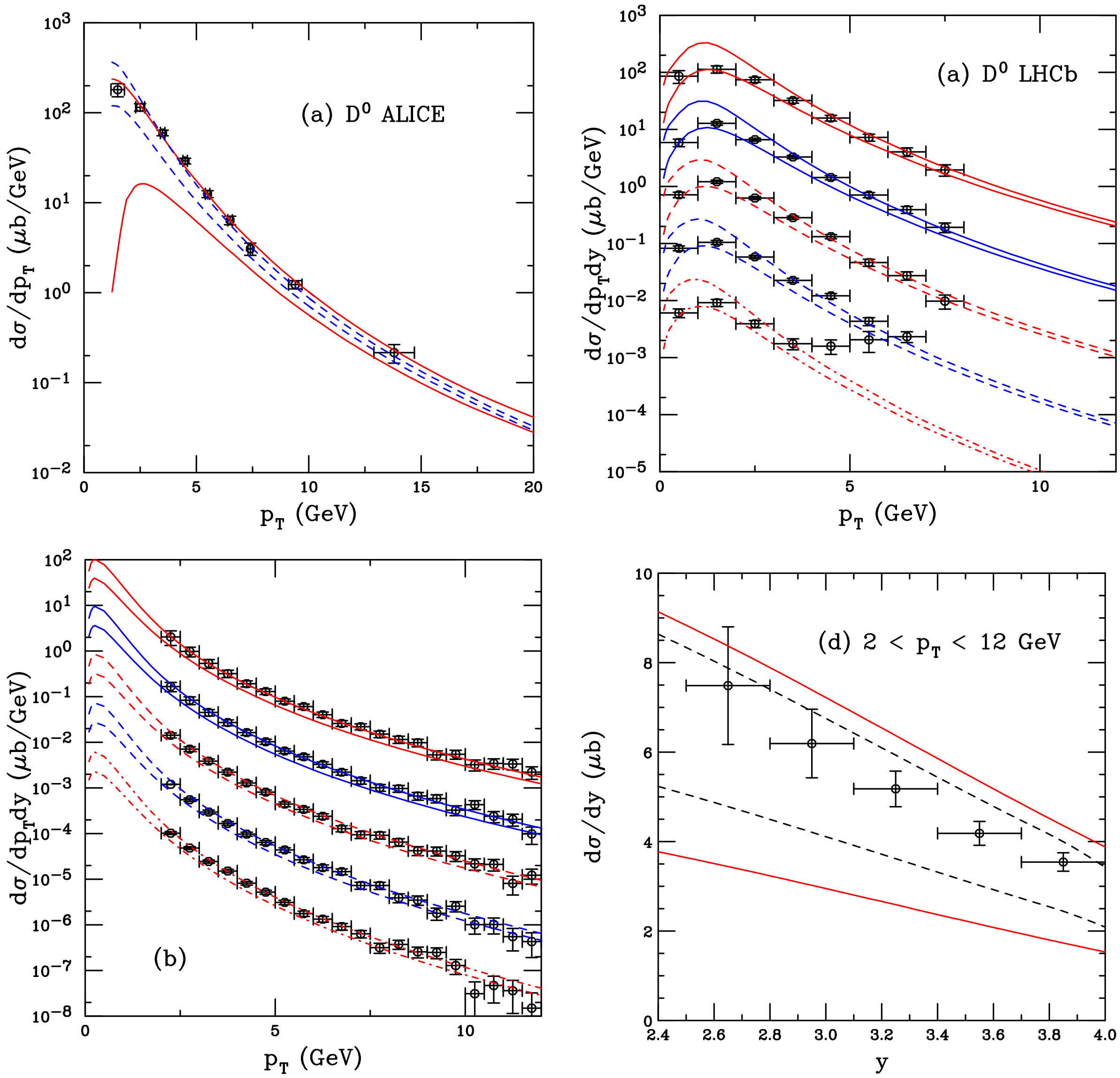

Figure 1: (Top Left) Our calculations are compared with the reconstructed ALICE D^0, (b) D^+, and (c) D^{*+} meson data [4] at $\sqrt{s} = 7$ TeV in $|y| \leq 0.5$. The FONLL uncertainty bands with $m = 1.5$ GeV are shown by the red solid curves while the blue dashed curves are calculated with the charm fit parameters. (Top Right) Our calculations are compared with the reconstructed LHCb D^0 [5] at $\sqrt{s} = 7$ TeV in the rapidity intervals: $2 < y < 2.5$ (solid red); $2.5 < y < 3$ (solid blue); $3 < y < 3.5$ (dashed red); $3.5 < y < 4$ (dashed blue); and $4 < y < 4.5$ (dot-dashed red). The curves are calculated with the charm fit parameters. The results are separated by a factor of 10. The lowest rapidity interval, $2 < y < 2.5$, is not scaled. (Bottom Left) The contributions to the p_T distributions in (a) divided into rapidity bins, from top to bottom: $2.5 < y < 2.8$ (solid red); $2.8 < y < 3.1$ (solid blue); $3.1 < y < 3.4$ (dashed red); $3.4 < y < 3.7$ (dashed blue); and $3.7 < y < 4$ (dot-dashed red). The top curves are shown at their calculated value, the others are scaled down by successive factors of 10. (Bottom Right) The sum of the contributions are compared with the FONLL set for charm (solid red) and that with $m = 1.27$ GeV (dashed black). From Ref. [3].

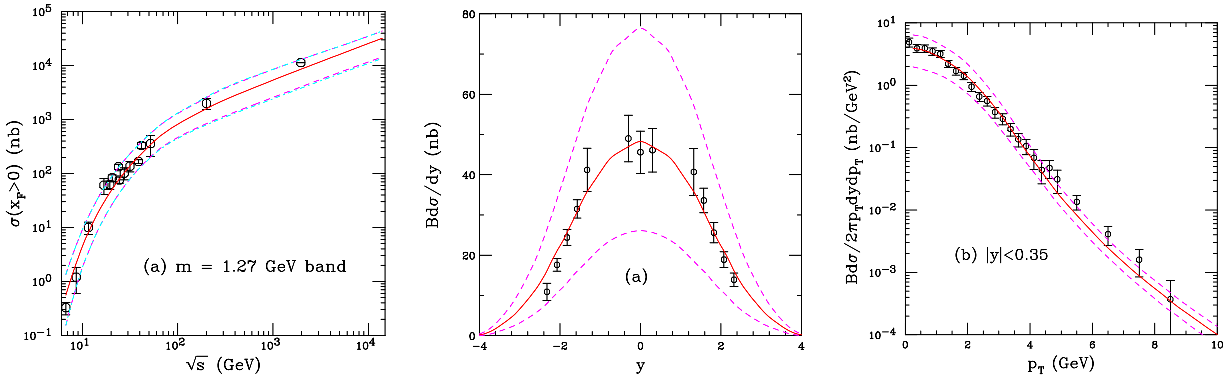

Figure 2: (Left) The uncertainty band on the forward J/ψ cross section as a function of $\sqrt{s}$ calculated with the new parameters. The dashed magenta curves and dot-dashed cyan curves show the extent of the corresponding uncertainty bands. The dashed curves outline the most extreme limits of the band. The J/ψ rapidity distribution (center) and the midrapidity p_T distributions (right) and their uncertainties calculated with the new parameters. The results are compared to PHENIX pp measurements at $\sqrt{s} = 200$ GeV [8]. No additional scaling factor has been applied. The solid red curve shows the central value while the dashed magenta curves outline the uncertainty band. A $\langle k_T^2 \rangle$ kick of 1.19 GeV^2 is applied to the p_T distribution. From Ref. [3].

1.2 Studies of the centrality dependence of nuclear shadowing

Tony Frawley, FSU graduate student Darren McGlinchey, and I have been studying the impact parameter (centrality) dependence of nuclear modifications of the parton densities (shadowing), in particular for J/ψ production in d+Au collisions at $\sqrt{s} = 200$ GeV [9].

Heretofore, the shadowing was assumed to have a linear dependence on impact parameter, either as a function of the nuclear thickness or the local density [10]. We have made an extensive study of this dependence and the implications on J/ψ production in d+Au collisions. We found that the centrality dependence is best described overall by the assumption that the shadowing is concentrated in the core of the nucleus,

$$M_{\rm shad} = 1 - \left(\frac{1 - R_g(x, Q^2)}{a(R,d)(1 + \exp((r_T - R)/d))} \right) , \quad (2)$$

where $R_g(x, Q^2)$ is gluon modification in the nucleus as a function of momentum fraction x and squared momentum transfer Q^2. A radius of $R = 2.4^{+0.53}_{-0.85}$ fm and a rather sharp edge, $d = 0.12^{+0.52}_{-0.10}$ fm, can describe the data rather well. This dependence contradicts that recently obtained by Eskola and collaborators in the EPS09s parameterization [11]. It would be interesting to see how this behavior agrees with other gluon-dominated production data at different energies.

We also extracted an effective absorption cross section as a function of rapidity. We see an increase in the effective absorption at both forward rapidity (which could be attributed to energy loss) and at backward rapidity, consistent with breakup of a growing color octet [9].

Our results are relevant for heavy flavor energy loss because assumptions about the centrality dependence of shadowing can affect the apparent level of energy loss.

1.3 Contribution to the dilepton continuum at the LHC

In earlier work, I calculated the relative contributions of semileptonic heavy flavor decays, Drell-Yan and thermal dileptons to the dilepton invariant mass continuum at RHIC and the LHC [12, 13, 14, 15]. I used the HVQMNR code [16] to update the heavy flavor contributions for a new look at the continuum makeup in Pb+Pb collisions at $\sqrt{s} = 2.76$ TeV with Vineet Kumar and Prashant Shukla of the CMS Collaboration [17]. We also included an estimate of the effect of heavy flavor energy loss on the dilepton spectrum, calculated by modifying the fragmentation function in the HVQMNR code.

We also included comparisons to Drell-Yan and thermal dilepton production. The Drell-Yan cross section was calculated to next-to-leading order. The thermal dilepton calculation uses the most recent estimates of the initial temperature for the LHC. The results, without experimental cuts included, are shown in Fig. 3.

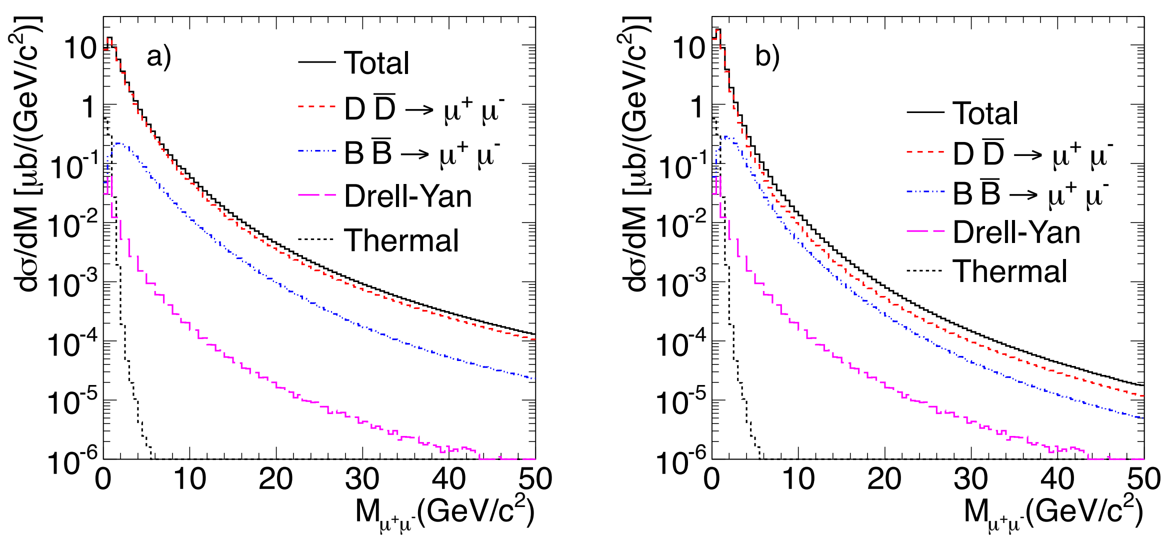

Figure 3: The invariant mass distributions for the four contributions to the dilepton spectra discussed here: semileptonic charm (red, short-dashed) and bottom (blue, dot-dot-dashed) decays, Drell-Yan (magenta, long-dashed) and thermal (black, dotted) dileptons along with the sum (black, solid) in Pb+Pb collisions per nucleon pair at $\sqrt{s_{NN}} = 2.76$ TeV. Left panel shows distributions without any final state energy loss, right panel is after including heavy quark energy loss in the medium. The per nucleon cross sections are given. No phase space or kinematic cuts are introduced. From Ref. [17].

1.4 Predictions for p+Pb at 5 TeV

At Quark Matter 2012 in Washington DC, I was tasked to compile predictions by JET Collaboration members and friends for the p+Pb run at the LHC in the winter of 2013. I collected the predictions in time to present them at the high p_T workshop in Wuhan, China in October 2012 and submit them to arXiv.org and for publication in January 2013, before the p+Pb run started. I collected predictions on charged hadrons; identified particles such as π^0, $K^{\pm}$, and $p/\overline{p}$; photons; jets; J/ψ; and gauge bosoms. The observables included individual distributions, ratios such as $R_{p\mathrm{Pb}}$, and correlation functions. A figure from the paper, compiling the $R_{p\mathrm{Pb}}$ predictions for unidentified charged particles, is shown in Fig. 4 [18]. The predictions are shown with the ALICE test beam data [19]. The paper [18] was published in International Journal of Modern Physics E. It has collected over 100 citations so far.

At the 2013 JET Collaboration meeting, it was suggested that I follow up this compilation with a further paper detailing how well the predictions compared to the experimental data. I followed up with this, including collecting more predictions for some observables than were available for the original paper, mostly for J/ψ and Υ, and getting updates on others, such as the charged particle multiplicity distributions in the same centrality bins as shown by the ATLAS Collaboration. I presented two conference talks with these updates, at Hard Probes 2013 in Stellenbosch, South Africa [20] and Quark Matter 2014 in Darmstadt, Germany [21].

In our compilation paper [18], it was shown that the charged particle pseudorapidity distributions exhibited a considerably steeper slope than the data, particularly in the direction of the lead nucleus. Further communication with Albacete and Dumitru [22] showed that the $dN_{\mathrm{ch}}/d\eta$ distribution depends strongly on the $y \longrightarrow \eta$ transformation. The rcBK calculation in Ref. [18] depends on this Jacobian, not uniquely defined in the color-glass condensate (CGC) framework. (It is necessary to assume a fixed minijet mass, related to the pre-hadronization/fragmentation stage.) Thus in the original compilation, they assumed the same transformation in pp and p+Pb collisions. The result shown in Fig. 5 shows the dependence of the distribution on the Jacobian. The open and filled squares represent the standard result [18] while the filled triangles are based on a "tuned" Jacobian with a modification of the hadron momentum by $\Delta P(\eta) = 0.04\eta[(N_{\mathrm{part}}^{\mathrm{proj}} + N_{\mathrm{part}}^{\mathrm{targ}})2 - 1]$. The results are essentially identical in the proton direction but differ considerably in the direction of the lead beam. The difference shows the sensitivity of this result to the mean mass and p_T of the unidentified final-state hadrons.

1.5 JET Collaboration Meeting and Summer School 2014

In June 2014, I chaired the JET Collaboration Meeting and Summer School at UC Davis. The website for the meeting and school can be found at http://jetsummer14.ucdavis.edu.

There were 26 registered students at the summer school from 14 institutions, both domestic and international. Most of the lecturers gave 3 hour-long lectures each but two of the experimental talks, on bulk properties, were one hour each. The theory lecturers were Zhongbo Kang (LANL) on pQCD and jets; Edmond Iancu (Saclay) on multiple gluon emission and jets; Jacopo Ghiglieri (McGill) on thermal QCD; Ulrich Heinz (Ohio State) on hydrodynamics; and Pengfei Zhuang (Tsinghua) on heavy flavor. The experimental lecturers were Marco van Leeuwen (NIKHEF) on hard probes and jets; Roy Lacey (Stony Brook) on bulk properties at RHIC; and Jiangyong Jia (Stony Brook) on bulk properties at the LHC. The interactions between students and lecturers was very good and all the students were happy with the school. There were also four student lectures on the last afternoon by Jiechen Xu (Columbia), Igor Kozlov (McGill), Chun Shen (OSU) and Christopher Plumberg (OSU).

1.6 INT Program: Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions

In September and October 2014 I was lead organizer for the month-long program, Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions, at the Institute for Nuclear Theory at the University of Washington. My co-organizers were Peter Petreczky, Tony Frawley and Enrico Scomparin, my co-conveners for the Quarkonium Working Group topical area of quarkonium in medium.

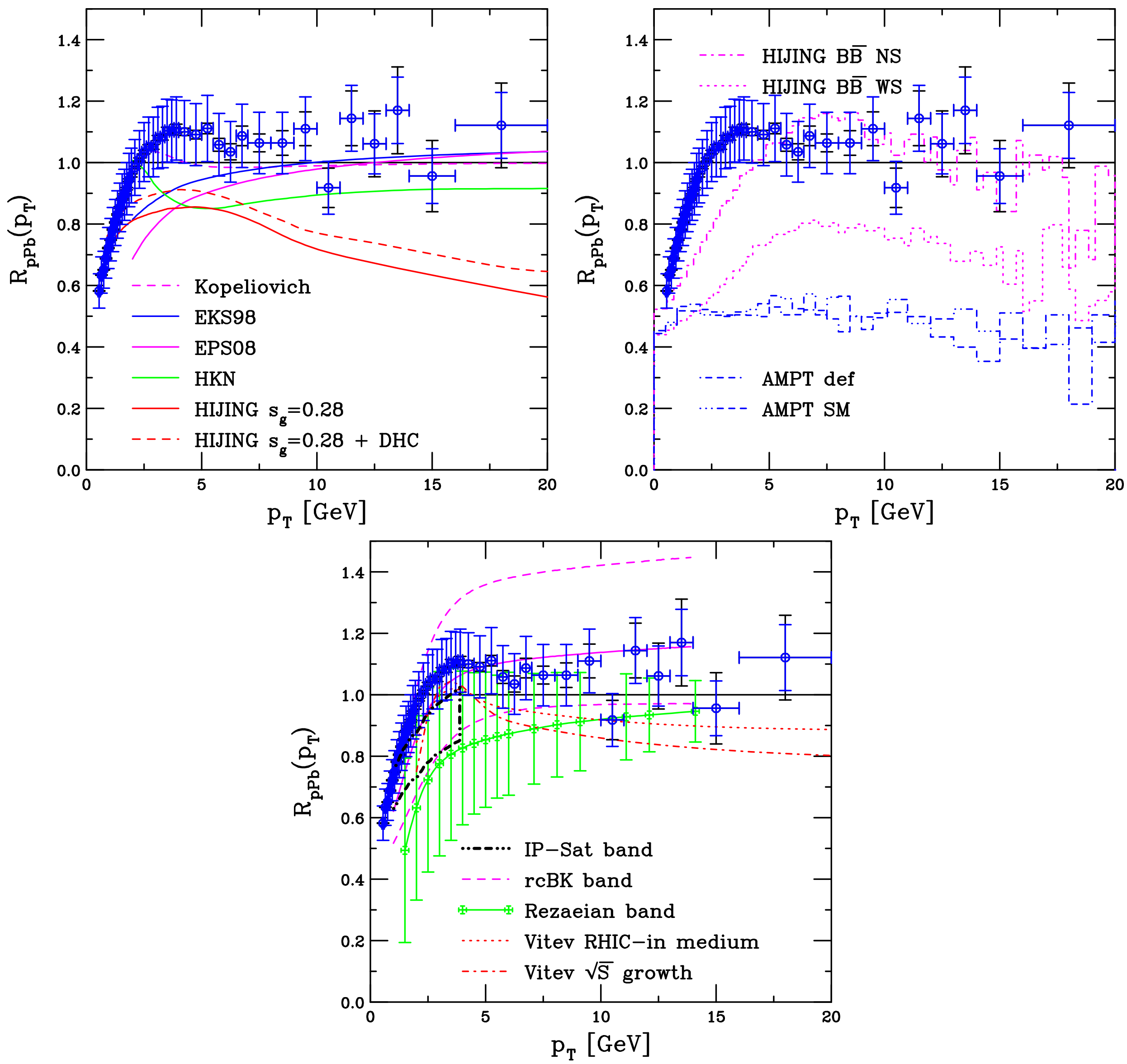

Figure 4: Charged particle $R_{p\mathrm{Pb}} p_T$ at $\sqrt{s_{_{NN}}} = 5.02$ TeV at $\eta \sim 0$. (Top left) Results with more ‘standard shadowing (labeled EKS98, EPS08 and HKN), scattering of a color dipole (labeled Kopeliovich) and the `HIJING2.1` shadowing parameterization are compared. The difference in the `HIJING2.1` curves depends on whether the hard scatterings are coherent or not. (Top Right) `HIJINGB`$\overline{\text{B}}$`2.0` with and without shadowing compared to `AMPT` default and with string melting. (Bottom) The band from rcBK saturation model calculations by Albacete *et al.* and Rezaeian with $N = 5$ and varying $\alpha_s^{\rm in}$ are compared to IP-Sat calculations by Tribedy and Venugopalan and calculations by Vitev *et al.* of cold matter effects with energy loss. The ALICE results from Ref. [19] are also shown. The systematic uncertainties are shown in blue, the statistical uncertainties are in black. Taken from Ref. [18].

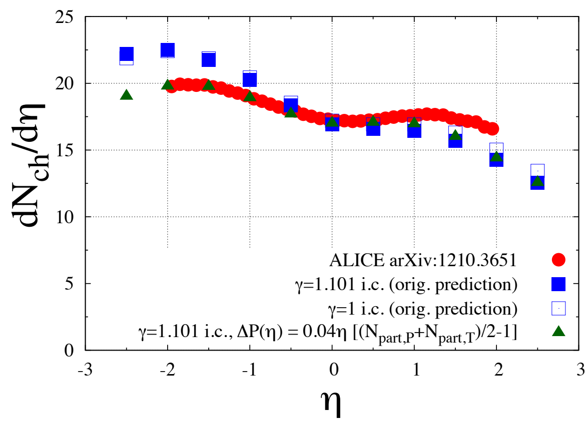

Figure 5: Charged particle pseudorapidity distribution at $\sqrt{s_{NN}} = 5.02$ TeV as a function of η with and without the tuned Jacobian. Courtesy of Albacete *et al.* [22].

The program was attended by 34 other participants spread out over the four week period.

The program covered the two main thrusts of studies of heavy quarks and quarkonium in heavy-ion physics: "hot matter" (effects specific to the high temperature medium produced in heavy-ion or nucleus-nucleus collisions) and "cold nuclear matter" (effects that are present already in proton-nucleus collisions and are a baseline against which hot matter effects must be compared as well as production of the heavy quarks and quarkonium (bound states of heavy quark-antiquark pairs) in perturbative QCD.) The program was structured so that the first two weeks were generally devoted to hot matter, especially lattice QCD. The second half was devoted to issues related to production and cold matter effects. An intense 2.5 day workshop was held from 29 September to 1 October. Although a theory program, experimentalists attended throughout, giving talks on recent data and future facilities.

Alexander Rothkopf (Heidelberg University) presented calculations of quarkonium spectral functions and static quark-antiquark potentials at $T > 0$, employing a novel Bayesian approach, see e.g. INT-PUB-14-046 and Fig. 6.

Enrico Scomparin (INFN Torino) discussed the ALICE Collaboration results from p+Pb collisions. In particular, he discussed $\psi(2S)$ production at forward and backward rapidity. At backward rapidity, they find significantly larger suppression than for the more strongly bound J/ψ, see the left-hand side of Fig. 7. As described by Torsten Dahms (TU Munich), the CMS Collaboration has also shown results for the $\psi(2S)$, but in Pb+Pb collisions, where, although in a different kinematic region (central rapidity and transverse momentum larger than 3 GeV/c) they find an enhancement of the yields compared to J/ψ, shown on the right-hand side of Fig. 7. A consistent interpretation of these data poses nontrivial problems.

1.7 Calculations for others

I have provided several calculations for use by JET members and associates. They are briefly described below.

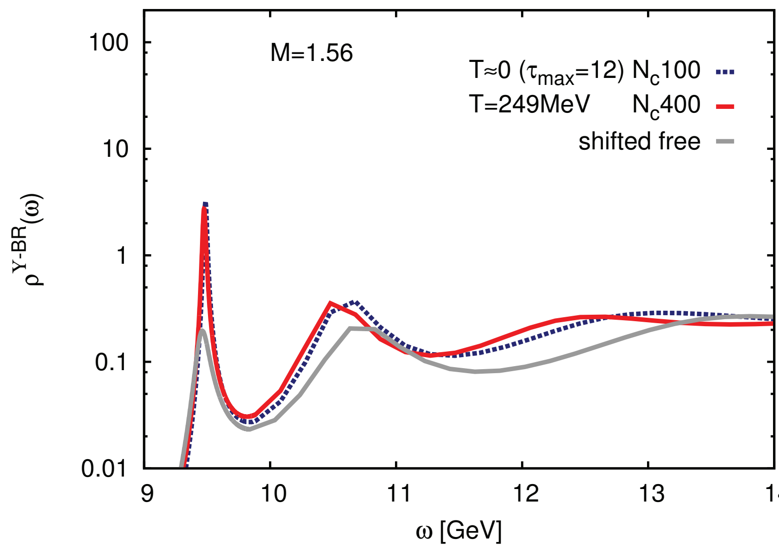

Figure 6: The Υ spectral function for $T = 249$ MeV and $T = 0$ both reconstructed with 12 points in the time direction using the novel Bayesian approach.

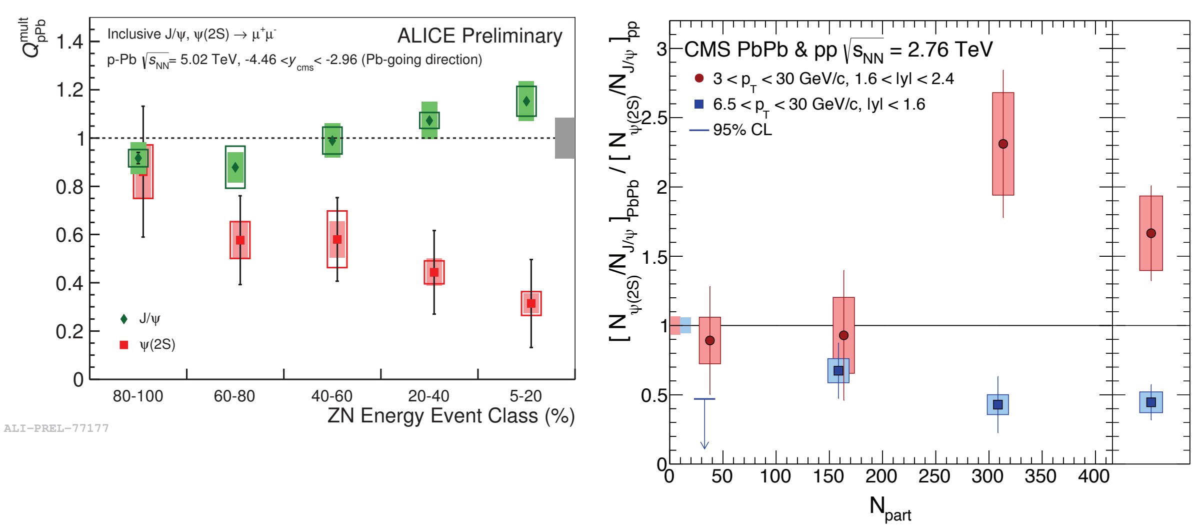

Figure 7: (Left) The nuclear modification factor $Q_{p\mathrm{Pb;mult}}$ for the J/ψ and $\psi(2S)$ states at backward (Pb-going) rapidity, measured by ALICE, as a function of the centrality of the p+Pb collision (0-20% corresponds to most central events). (Right) The ratio $\psi(2S)/J/\psi$ for Pb+Pb collisions, normalized to the same quantity in pp, plotted as a function of N_{part}. The results are presented for two different p_T ranges. The right-most points correspond to the centrality-integrated sample.

1.7.1 CUJET1.0

Alessandro Buzzatti and Miklos Gyulassy have developed a new Monte Carlo pQCD tomographic code, CUJET1.0 [23]. CUJET1.0 extends the opacity expansion developed by the Columbia group [24, 25, 26] by including new dynamical features. These features require additional computational power most easily accessible via Monte Carlo methods. I provided the charm and bottom quark distributions used as input for CUJET1.0 in this paper.

1.7.2 Predictions for low energy RHIC runs

Daniel Kikola of the STAR Collaboration contacted me in late 2011 to ask for predictions of the heavy flavor contribution to the non-photonic electron spectra at $\sqrt{s} = 39$ and 62 GeV. I provided the central results as well as uncertainty bands on the semileptonic decays of $D \to lX$, $B \to lX$ and $B \to DX \to lX'$. The bottom quark contribution is rather small, particularly at $\sqrt{s} = 39.6$ GeV which is not far above the production threshold where the production cross section is still a strong function of $\sqrt{s}$. Since we have completed the analysis discussed in section 1.1, I also included the uncertainty on the $D \to lX$ decay based on these results.

The results for the sum of all single lepton contributions from heavy flavor decays is shown in Fig. 2 for $\sqrt{s} = 39$ and 62 GeV. The results with both the FONLL fiducial sets and those derived from the fit shown in Fig. 1 are given in Fig. 2. The fit result is somewhat higher at low p_T but, as p_T increases, the slopes become increasingly similar. Note, however, that the fits provide a narrower uncertainty band.

I calculated J/ψ production as a function of rapidity and p_T at $\sqrt{s} = 39$ and 62 GeV for Mike Leitch (PHENIX) and Lijuan Ruan (STAR). These calculations were based on the J/ψ fits in Ref. [3]. PHENIX published the comparison in Ref. [27].

1.7.3 STAR at 500 GeV

I provided FONLL calculations of D meson distributions in pp collisions at $\sqrt{s} = 500$ GeV to be compared to the STAR measurements. The calculations were made with the new mass and scale parameters found in our fit [3]. The results were first shown by David Tlusty at the Hard Probes meeting in Italy and published in the Quark Matter proceedings [28].

1.7.4 Cold matter effects on Υ production

Using the fiducial b quark parameters, $m = 4.75$ GeV, $\mu_F/m = \mu_R/m = 1$, I calculated the uncertainty in the ratio $R_{\rm dAu}$ due to shadowing effects to next-to-leading order in the rapidity distribution for the PHENIX collaboration. I also provided an estimate of absorption effects, as requested by the collaboration. The comparison of the data to my calculations is published in Ref. [29].

1.7.5 Convener/editor for Confinement X report

In July 2013, I was asked to contributed to a document based on results presented at the Confinement X meeting from 2012 on "QCD-driven Strongly Coupled Physics: challenges, scenarios and perspectives". The document is organized in topical sections with an aim to summarize the latest achievements/highlights in the field; the most important open problems; the most promising theoretical and experimental avenues for progress; the requirements of experiments from theory and vice versa. After my initial contribution, I become a convener for the chapter on deconfinement. The full document can be found in Ref. [30].

1.7.6 ALICE and LHCb: J/ψ and Υ production in cold matter

I calculated cold matter (shadowing) effects on J/ψ and Υ production in p+Pb collisions at $\sqrt{s_{NN}} =$ 5 TeV for the ALICE and LHCb Collaborations. They have analyzed the data both in the normal comparison to an extrapolated pp distribution (since there is no pp data at $\sqrt{s_{NN}} = 5$ TeV), the $R_{p\mathrm{Pb}}$ observable, and a comparison of the forward and backward regions, relying only on their measurements in a common rapidity window, the forward-backward ratio, R_{FB}. Comparisons to the calculations can be found in Refs. [31, 32, 33, 34, 35].

1.7.7 Predictions for J/ψ production in ATLAS

I calculated J/ψ production as a function of p_T in several rapidity bins at $\sqrt{s} = 7$ TeV for the ATLAS Collaboration. These calculations were based on the J/ψ fits in Ref. [3] and were presented by the collaboration at the Hard Probes meeting at McGill University in Montreal, Canada in June 2015 [36].

2 List of Publications and Talks

Publications:

1. Heavy quarkonium: progress, puzzles and opportunities, N. Brambilla *et al.*, Eur. Phys. J. C **71** (2011) 1.

2. Initial-state quark energy loss from Drell-Yan production in proton-proton and proton-nucleus collisions, H. K. Wörhi, P. Faccioli, C. Lourenę and R. Vogt, *Quarkonium 2010: Three Days of Quarkonium Production in pp and pA collisions*, Nucl. Phys. Proc. Suppl. **214** (2011) 88.

3. The status of open heavy flavor production at RHIC, R. Vogt, *Quarkonium 2010: Three Days of Quarkonium Production in pp and pA collisions*, Nucl. Phys. Proc. Suppl. **214** (2011) 129.

4. Quarkonia as a multi-purpose tool, R. Vogt, *Three Days of Quarkonium Production in pp and pA collisions*, Nucl. Phys. Proc. Suppl. **214** (2011) 147.

5. Quarkonium production at high energy proton-proton and proton-nucleus colliders, J.-P. Lansberg *et al.*, *Quarkonium 2010: Three Days of Quarkonium Production in pp and pA collisions*, Nucl. Phys. Proc. Suppl. **214** (2011) 3.

6. Charm and bottom production from fixed-target to LHC energies, R. Nelson, R. Vogt, C. Lourenço and H. K. Wöhri, *4*$^{\mathrm{th}}$ *International Conference on Hard and Electromagnetic Probes of High Energy Nuclear Collisions*, Nucl. Phys. A **855** (2011) 400.

7. J/ψ Production and Absorption in pA and d+Au Collisions, by R. Vogt, C. Lourenço and H. K. Wöhri, *4*$^{\mathrm{th}}$ *International Conference on Hard and Electromagnetic Probes of High Energy Nuclear Collisions*, Nucl. Phys. A **855** (2011) 453.

8. Dilepton-tagged jets in heavy-ion collisions at the LHC, C. Mironov, P. Constantin, M. Castro, G.J. Kunde and R. Vogt, J. Phys. G **38** (2011) 065002.

9. Proton-nucleus collisions at the LHC: Scientific opportunities and requirements, C. A. Salgado *et al*, J. Phys. G **39** (2012) 015010 [arXiv:1105.3919 [hep-ph]].

10. Prospects for quarkonia production studies in U+U collisions, D. Kikola, G. Odyniec and R. Vogt, Phys. Rev. C **84** (2011) 054907 [arXiv:1111.4693 [nucl-ex]].

11. Charmonium Production and Corona Effect, S. Digal, H. Satz and R. Vogt, Phys. Rev. C **85** (2012) 034906.

12. Narrowing the uncertainty on the total charm cross section and its effect on the J/ψ cross section, R. E. Nelson, R. Vogt and A. D. Frawley, Phys. Rev. C **87** (2013) 014908.

13. Components of the dilepton continuum in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, by V. Kumar, P. Shukla and R. Vogt, Phys. Rev. C **86** (2012) 054907.

14. Viewpoint: New temperature probe for quark-gluon plasma, by R. Vogt, Physics **5** (2012) 132.

15. Impact parameter dependence of the nuclear modification of J/ψ production in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, D. C. McGlinchey, A. D. Frawley and R. Vogt, Phys. Rev. C **87** (2013) 054910.

16. Predictions for p+Pb collisions at $\sqrt{s_{NN}} = 5$ TeV, J. L. Albacete *et al*, edited by R. Vogt, Int. J. Mod. Phys. E **22** (2013) 1330007.

17. Improving the J/ψ Production Baseline at RHIC and the LHC, by R. Vogt, R. E. Nelson and A. D. Frawley, $5^{\rm th}$ *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*, Nucl. Phys. A **910-911** (2013) 231.

18. Heavy Flavor and Quarkonium Production at RHIC and the LHC, by R. E. Nelson, R. Vogt and A. D. Frawley, *Quark Confinement and the Hadron Spectrum X*, PoS Confinement X (2012) 203.

19. Open and Hidden Heavy Flavor Production in pp, pA and AA Collisions, by R. Vogt, *$14^{\rm th}$ International Conference on Strangeness in Quark Matter*, J. Phys. Conf. Ser. **509** (2014) 012007.

20. J/ψ's Are Jazzy, by R. Vogt, *45 Years of Nuclear Theory at Stony Brook: A Tribute to Gerald E. Brown*, Nucl. Phys. A **928** (2014) 222.

21. Predictions for p+Pb Collisions at $\sqrt{s_{NN}} = 5$ TeV: Expectations vs. Data, by R. Vogt, $6^{\rm th}$ *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*, Nucl. Phys. A **932** (2014) 494.

22. Predictions for p+Pb collisions at $\sqrt{s_{NN}} = 5$ TeV: Expectations vs. data, by R. Vogt (JET Collaboration), *Quark Matter 2014,* $24^{\rm th}$ *International Conference on Ultrarelativistic Nucleus-Nucleus Collisions*, Nucl. Phys. A **931** (2014) 371.

23. QCD and Strongly Coupled Gauge Theories: Challenges and Perspectives, by N. Brambilla, R. Vogt *et al.*, Eur. Phys. J. C **74** (2014) 2981.

24. Gluon shadowing effects on J/ψ and Υ production in p+Pb collisions at $\sqrt{s_{NN}} = 115$ GeV and Pb+p collisions at $\sqrt{s_{NN}} = 72$ GeV at AFTER@LHC, by R. Vogt, Adv. High Energy Phys., in press.

25. A review of the intrinsic heavy quark content of the nucleon, by S. J. Brodsky, R. Vogt *et al.*, arXiv:1504.06287 [hep-ph], Adv. High Energy Phys., in press.

26. Heavy-flavour and quarkonium production in the LHC era: from proton-proton to heavy-ion collisions, by A. Andronic, R. Vogt *et al.*, arXiv:1506.03981 [nucl-ex].

27. Quarkonia suppression in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, by V. Kumar, P. Shukla and R. Vogt, accepted for publication in Phys. Rev. C.

Talks:

1. *Quarkonium 2010: Three Days of Quarkonium Production in pp and pA collisions*, Ecole Polytechnique, Palaiseau, France, 7/10. Talks: Quarkonium as a Tool: What Kind of Tool Would It Be?; Open Heavy Flavor Production at RHIC.

2. *4*$^{\rm th}$ *International Conference on Hard and Electromagnetic Probes of High Energy Nuclear Collisions*, Eilat, Israel, 10/10. Talk: J/ψ Production and Absorption in pA and d+Au Collisions.

3. APS Division of Nuclear Physics Fall Workshop, Santa Fe, NM, 11/10. Talk: Fraction of J/ψ production from B decays at RHIC and LHC.

4. *International Workshop on Heavy Quark Production in Heavy-Ion Collisions*, Purdue University, West Lafayette, IN, 1/11. Invited talk: J/ψ production and absorption in pA and d+Au collisions.

5. *Quarkonium Production: Probing QCD at the LHC*, Institute of High Energy Physics, Vienna, Austria, 4/11. Talk: Estimating Uncertainties on Quarkonium production in the Color Evaporation Model. Invited theory summary talk: Where Are We Going and How Do We Get There? Making A Quarkonia Roadmap.

6. *Quarkonium Production in Elementary and Heavy Ion Collisions*, Brookhaven National Laboratory, Upton, NY, USA, 6/11. Invited talk: Estimating the Uncertainty on J/ψ Production,

7. JET Collaboration meeting, Duke University, Durham, NC, USA, 6/11. Talk: Heavy Quark Discussion.

8. *EMMI Workshop on Deconfined Matter*, Acitrezza, Italy, 9/11. Invited talk: Uncertainty Quantification of Quarkonium and Heavy Flavor Production.

9. APS April Meeting, Atlanta, GA, USA, 3-4/12. Talk presented by UC Davis graduate student Randy Nelson: Determining the uncertainty on the charm cross section and the effect on the J/ψ cross section.

10. 4$^{\rm th}$ *Berkeley School of Collective Dynamics in High-Energy Collisions*, LBNL, Berkeley, CA, USA, 5/12. Invited talk: Charmonium Production.

11. 5$^{\rm th}$ *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions*, Cagliari, Sardinia, Italy, 5-6/12. Talk: Improving the J/ψ Production Baseline at RHIC and the LHC.

12. *Confinement X*, 10$^{\rm th}$ Quark Confinement and the Hadron Spectrum, Munich, Germany, 10/12. Invited talk: Heavy Flavor and Quarkonium Production at RHIC and the LHC.

13. *Hot Topics in Hot Matter*, 70$^{\rm th}$ Birthday Symposium for Itzhak Tserruya, Weizmann Institute, Rehovot, Israel, 10/12. Invited talk: Heavy Flavor and Quarkonium Production at RHIC and the LHC.

14. 8^{th} International Workshop on High p_T Physics at the LHC, Central China Normal University, Wuhan, China, 10/12. Invited talk: Predictions for $\sqrt{s_{_{NN}}} = 5$ TeV p+Pb Collisions.

15. NHEP seminar, LLNL, Livermore, CA, USA, 1/13: Predictions for $\sqrt{s_{_{NN}}} = 5$ TeV p+Pb Collisions.

16. Nuclear Group seminar, UC Davis, Davis, CA, USA, 1/13: Predictions for $\sqrt{s_{_{NN}}} = 5$ TeV p+Pb Collisions.

17. ECT* Program *Physics at A Fixed Target Experiment using the LHC beam*, Trento, Italy, 2/13. Invited talk: Heavy Quarks and Quarkonia in pA Collisions.

18. GHP 2013, Denver, CO, USA, 4/13. Talk: J/ψ Production in Cold Nuclear Matter.

19. ECT* Program *Workshop on proton-nucleus collisions at the LHC*, Trento, Italy, 5/13. Invited talk: Predictions for p+Pb Collisions at the LHC.

20. Seminar at the University of Manchester, Manchester, UK, 7/13: Open and Hidden Heavy Flavor Production in pp, pA and AA Collisions

21. Seminar at the University of Birmingham, Birmingham, UK, 7/13: Open and Hidden Heavy Flavor Production in pp, pA and AA Collisions.

22. Strangeness in Quark Matter, University of Birmingham, Birmingham, UK, 7/13. Invited plenary talk: Open and Hidden Heavy Flavor Production in pp, pA and AA Collisions.

23. 6^{th} *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions* Stellenbosch, South Africa 11/13. Talk: Predictions for p+Pb Collisions at $\sqrt{s_{NN}} = 5$ TeV: Expectations vs. Data.

24. *45 Years of Nuclear Theory at Stony Brook: A Tribute to Gerald E. Brown* State University of New York at Stony Brook, Stony Brook, NY, USA, 11/13. Talk: J/ψ's Are Jazzy.

25. *Quark Matter 2014,* 24^{th} *International Conference on Ultrarelativistic Nucleus-Nucleus Collisions.* Talk: Predictions for p+Pb collisions at $\sqrt{s_{NN}} = 5$ TeV: Expectations vs. data.

26. Saclay Seminar, 6/14. Predictions for p+Pb Collisions at $\sqrt{s_{NN}} = 5$ TeV: Expectations vs. Data.

27. JET Collaboration Meeting and Summer School, UC Davis, Davis, CA, 6/14. Talk: Update on p+Pb Collisions: Expectations vs. Data.

28. *Future directions in forward heavy-ion physics* & *The LHC Forward Physics and Diffraction WG meeting*, University of Kansas, Lawrence, KS, 9/14. Student lecture: The Ins and Out of Nuclear Parton Densities. Invited talk: Quarkoniun and jet production in studies of nucleon/nuclear parton densities.

29. 10^{th} *International Workshop on Heavy Quarkonium*, CERN, Geneva, Switzerland, 11/14. Talk: Quarkonium in cold nuclear matter and nuclear parton densities. I am a convener of the in-medium working group.

30. ECT* Program *Heavy Quark Physics in Heavy-Ion Collisions: Experiments, phenomenology and theory*, Trento, Italy, 3/15. Invited talk: Cold Nuclear Matter Effects on Open and Hidden Heavy Flavor Production in p+Pb Collisions.

31. GHP 15, Baltimore, MD, 4/15. I was a member of the organizing committee. Talk: Nuclear Modification of Quarkonium Production in p+Pb Collisions at the LHC.

Meeting Organization:

1. Member of the International Advisory Committee, Quarkonium Production: Probing QCD at the LHC, Institute of High Energy Physics, Vienna, Austria, April 2011.
2. Co-chair of GHP2011, Fourth Workshop of the APS Topical Group on Hadronic Physics, Anaheim, CA, April 2011.
3. Session convener, Quarkonia in Media, 8$^{\text{th}}$ International Workshop on Heavy Quarkonium, GSI, Darmstadt, Germany, October 2011.
4. Member of the Program Committee for the APS April Meeting, Atlanta, GA, USA, 3-4/12. I also chaired a session and ran the GHP Business Meeting.
5. Member of the Organizing Committee, GHP13, Denver, CO, 4/13.
6. Session convener, Quarkonia in Media, 9$^{\text{th}}$ International Workshop on Heavy Quarkonium, Beijing, China, 4/13.
7. Member of the International Advisory Committee for the 6$^{\text{th}}$ *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions* in Stellenbosch, South Africa 11/13.
8. Chair of JET Collaboration Meeting and Summer School, UC Davis, Davis, CA, 6/14.
9. Lead organizer of INT program: *Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions*, Seattle, WA, 9-10/14. My co-organizers were P. Petreczky, A. D. Frawley and E. Scomparin.
10. Session convener, Quarkonia in Media, 10$^{\text{th}}$ International Workshop on Heavy Quarkonium, CERN, Geneva, Switzerland, 11/14.
11. Member of the Organizing Committee, GHP15, Baltimore, MD, 4/15.
12. Member of the International Advisory Committee for CHARM 2015, Wayne State University, Detroit, MI, 5/15.
13. Member of the International Advisory Committee for the 7$^{\text{th}}$ *International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions* in Montreal, Canada, 6/15.

Other

1. Chair-Elect of GHP, 2010-2011
2. Chair of GHP Program Committee 2011
3. Chair of GHP, 2011-2012
4. Chair of GHP Dissertation Award Committee 2012

5. Past Chair of GHP, 2012-2013
6. Chair of GHP Nominating Committee 2013
7. Member of GHP Fellowship Committee 2013
8. Member of GHP Dissertation Award Committee 2014
9. Physical Review C Editorial Board member, 1/13 - present.
10. Member of PhD Committee for Guillermo Breto Rangel of UC Davis, 2013. Guillermo's Υ analysis for the CMS Collaboration was the basis for the Physical Review Letter highlighted in my invited Viewpoint article for Physics [37].
11. Member of PhD Committee for Michael Gardner, Samantha Brovko, Evan Sangeline, and Rylan Conway, UC Davis, 2014. (Evan was the winner of the RHIC/AGS Thesis Award in 2015.)

References

[1] R. Vogt, Eur. Phys. J. Special Topics **155** (2008) 213.

[2] R. Vogt, Eur. Phys. J. C **61** (2009) 793.

[3] R. E. Nelson, R. Vogt and A. D. Frawley, Phys. Rev. C **87** (2013) 014908.

[4] B. Abelev *et al.* [ALICE Collaboration], JHEP **1201** (2012) 128.

[5] M. Schmelling and P. Spradlin [LHCb Collaboration], LHCb-CONF-2010-013.

[6] M. Cacciari, P. Nason and R. Vogt, Phys. Rev. Lett. **95** (2005) 122001.

[7] B. Abelev *et al.* [ALICE Collaboration], Phys. Lett. B **708** (2012) 265.

[8] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. D **85** (2012) 092004.

[9] D. C. McGlinchey, A. D. Frawley and R. Vogt, Phys. Rev. C **87** (2013) 054910.

[10] S. R. Klein and R. Vogt, Phys. Rev. Lett. **91** (2003) 142301.

[11] I. Helenius, K. J. Eskola, H. Honkanen and C. A. Salgado, JHEP **1207** (2012) 073.

[12] R. Vogt, B. V. Jacak, P. L. McGaughey, P. V. Ruuskanen, Phys. Rev. D **49** (1994) 3345.

[13] S. Gavin, P. L. McGaughey, P. V. Ruuskanen, and R. Vogt, Phys. Rev. C **54** (1996) 2606.

[14] Z. Lin, R. Vogt and X. N. Wang, Phys. Rev. C **57** (1998) 899.

[15] Z. Lin and R. Vogt, Nucl. Phys. B **544** (1999) 339.

[16] M. L. Mangano, P. Nason, and G. Ridolfi, Nucl. Phys. B **373** (1992) 295.

[17] V. Kumar, P. Shukla and R. Vogt, Phys. Rev. C **86** (2012) 054907.

[18] J. L. Albacete *et al*, Int. J. Mod. Phys. E **22** (2013) 1330007.

[19] B. Abelev *et al.* [ALICE Collaboration], Phys. Rev. Lett. **110** (2013) 082302.

[20] R. Vogt, Nucl. Phys. A **932** (2014) 494.

[21] R. Vogt (JET Collaboration), Nucl. Phys. A **931** (2014) 371.

[22] J. Albacete and A. Dumitru, private communication.

[23] A. Buzzatti and M. Gyulassy, Phys. Rev. Lett. **108** (2012) 022301.

[24] M. Gyulassy, P. Levai, and I. Vitev, Nucl. Phys. B **594** (2001) 371.

[25] M. Djordjevic and M. Gyulassy, Nucl. Phys. A **733** (2004) 265.

[26] S. Wicks, W. Horowitz, M. Djordjevic and M. Gyulassy, Nucl. Phys. A **784** (2007) 426.

[27] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. C **86** (2012) 064901.

[28] D. Tlusty [STAR Collaboration], Nucl. Phys. A **904-905** (2013) 639c.

[29] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **109** (2012) 242301.

[30] N. Brambilla *et al.*, Eur. Phys. J. C **74** (2014) 2981.

[31] B. Abelev *et al.* (ALICE Collaboration), JHEP **1402**, 073 (2014).

[32] J. Adam *et al.* (ALICE Collaboration), JHEP **1506**, 055 (2015).

[33] R. Aaij *et al.* (LHCb Collaboration), JHEP **1402**, 072 (2014).

[34] B. B. Abelev *et al.* (ALICE Collaboration), Phys. Lett. B **740**, 105 (2014).

[35] R. Aaij *et al.* (LHCb Collaboration), JHEP **1407**, 094 (2014).

[36] G. Aad *et al.* (ATLAS Collaboration), arXiv:1505.08141 [hep-ex].

[37] R. Vogt, Physics **5** (2012) 132.